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MICROSEISMICITY ASSOCIATED WITH DEVELOPMENT OF GULF COAST GEOPRESSURED-GEOTHERMAL ENERGY WELLS: TWO STUDIES, PLEASANT BAYOU NO. 2 AND DOW L. R. SWEEZY NO. 1.

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ABSTRACT

Continuous microseismic monitoring of the regions around the Pleasant Bayou No. 2 well in Brazoria County, Texas and the Dow L. R. Sweezy No. 1 well (Bayou Parcperdue) in Vermilion Parish, Louisiana has been conducted by Teledyne Geotech since September, 1978 and August, 1980 at the two sites respectively. The two principal objectives of these research programs are (1) to assess normal ambient regional seismicity characteristics prior to high-volume brine production, and (2) to evaluate the seismological impact of high-volume brine production and disposal from these geopressured wells. Because neither of these wells has undergone sustained major brine production, the principal results of the microseismic monitoring relate to the first objective.

INTRODUCTION

Commercial utilization of the energy associated with the vast quantities of geopressured-geothermal brines underlying the Gulf Coast strongly depends on the production and the safe disposal of these highly saline fluids at individual well rates generally of the order of 3,000 cubic meters per day. Such volumetric productions would alter substantially the state of subsurface stress possibly resulting in regional ground subsidence and induced seismic activity. To investigate the seismic hazards associated with the development of this resource, Teledyne Geotech, with the authorization of the Texas Bureau of Economic Geology and the Louisiana Geological Survey has conducted seismic monitoring programs in the regions around the Pleasant Bayou No. 2 well in Brazoria County, Texas, and the DOW L. R. Sweezy No. 1 well (Bayou Parcperdue) in Vermilion Parish, Louisiana. These two experimental programs constitute complementary end members of a continuum of possible resource development scenarios. The Brazoria Fairway is an extremely large-volume resource and if significant permeability barriers are not encountered should be capable of high volume brine production for many years. The Parcperdue Prospect, on the other hand, is a limited volume resource which should be depleted within a few months of high volume production. Although it is likely that every prospect must be handled on an individual basis, valuable insight into potential hazards associated with brine production from a variety of other geopressured/geothermal Gulf Coast fairways and prospects may be gleaned from these two prototype experiments. In addition, we believe that improved understanding of growth fault and subsidence mechanics as well as delineation of possible reservoir barriers are likely side benefits of these studies.

The Brazoria and Parcperdue Seismic Networks

The seismic arrays established for these two regions are illustrated in figure 1a (Brazoria, Texas) and figure 1b (Parcperdue, Louisiana). Each network consists of five short-period vertical motion sensors (seismometers) which are mounted in boreholes 100 feet deep to reduce surface noise interference. The locations of these sensors are indicated in figure 1 by the the solid triangles. The vibrations sensed by the seismometers are amplified and the signals conditioned for phone line telemetry to the Teledyne Geotech laboratories at Garland, Texas. There, the individual channels are continuously recorded on microfilm and on magnetic tape. The overall frequency response of each station is illustrated in figure 2. The peak magnifications for the Brazoria and Parcperdue array stations are approximately 100,000 and 50,000 respectively. The differences in network sensitivities reflect the differences in ambient local ground noise. The Brazoria array has been nearly continously operational since September, 1978 and the Parcperdue array since August 1980.

To assess the nature of the regional seismicity at each test well, the network analog data are scanned daily for events of interest. All events which may be local microearthquakes or explosions are then processed to determine their hypocentral locations (geographical and depth) and their relative sizes. It is important to realize that networks with such limited spatial dimensions and so few stations are not capable of delivering statistically high-resolution hypocenter locations, but are dominantly designed to resolve the question of whether or not local seismicity above a certain magnitude exists. The minimum magnitude threshold for these arrays is approximately a 1.0 earthquake (roughly an energy release of 2.2×10^7 ergs), although under unusual circumstances (i.e. low ambient noise) microearthquakes with magnitudes as low as 0.5 may be resolvable. Because location capabilities are dependent on resolution of body waves (P or S waves) for an event on at least four separate instruments, and on utilization of an accurate velocity structure model, the location resolution and detection resolution frequently differ by more than a full magnitude unit. Throughout this paper we shall attempt to identify the appropriate resolution reference. Similarly, it is important to realize that rough epicenter (surface coordinates) locations are possible using surface waves (Rayleigh), but depth location is only possible using sophisticated modeling procedures with surface waves which are not appropriate to these data.

Observational Results

Because neither the Pleasant Bayou No. 2 nor the L. R. Sweezy No. 1 well has undergone long-term high-volume production, very little can be said regarding the relationship of draw-down and induced seismicity. However, with a combined array observation period of some fifty months and a few short-term production tests at the Brazoria site, some interesting observations have been made, and some tentative conclusions can be drawn. In this section, we shall review the significant observations from the network data and shall follow in the next section with tentative conclusions and hypothesis. We have attempted to separate the two categories to confusion of actual observations from educated speculations.

(1) Natural (non-induced) microearthquake activity at both the Brazoria and Parcperdue sites is very low and the size (magnitude) of the events is very small. No events have been recorded with magnitudes larger than 1.5.

(2) Positive identification of normal natural events is often very difficult. Microearthquakes have been recorded with normal high-frequency body waves (see figure 3) and with unusually low-frequency body waves (see figure 4). Some events have been tentatively identified as earthquakes because they occurred at peculiar times of day and/or were not part of a normal exploration explosion series. Their frequency content, however, would normally suggest an explosive source. Body waves frequently have signal to noise ratios less than 1:1 requiring location of the event using surface wave techniques.

(3) Unusual "rumbling" events have occurred at the Brazoria array (figure 5). These events have no clearly identifiable body waves, and almost always indicate a propagation direction across the array by the order of arrivals. They usually occur as swarms and show a vague correlation of sustained amplitude and duration. Frequently, these events will be followed by trains of one hertz waves lasting several minutes. There is no obvious increase or decrease in the number or size of these events in the sequence. Some times these rumble events will be followed by one or more distinct but very small microearthquake-type events.

(4) The spatial distribution of events which could be identified either clearly as microearthquakes or could not be identified positively as explosive sources show a strong correlation with known growth fault locations (figures 1a, 1b). No microseismicity at the Brazoria array located at the growth faults east or northeast of the test well. This may be significant or may only indicate the strongly preferred coverage of the array.

(5) Following brief brine productions at the Pleasant Bayou No. 2 well, small events occurred thirty to sixty days after shut-in and appeared to locate further from the well-head as a function of time. Also, with the proviso that depth constraints are poor, there appears to be a migration of activity from the geopressured zone upward with increasing time following shut-ins.

(6) Surface waves have frequency-dependent group velocities which are transonic in the range between 10 hertz and 1 hertz (figure 6). The Airy phase (minimum group travel time) has a dominant frequency of 5 hertz and is extremely subsonic. Because of this, the coupling between earth-transmitted Rayleigh waves and air-transmitted acoustic waves is very complex, making utilization of surface waves for analysis difficult.

(7) The significant variation in appearance of a common event on different stations indicates that local attenuation characteristics are quite complex.

Tentative Conclusions and Speculations

Based on the observational results to date and other knowledge, we would like to suggest some tentative conclustions and speculations for consideration.

(1) Both high-stress-drop and low-stress-drop microearthquakes have been observed. Figure 3 is an example of a high-stress-drop, fast-rupture-velocity microearthquake recorded at the Parcperdue array. The resolution of the hypocenter for this earthquake on 27 March 1981 is quite good and strongly suggests association with the southernmost growth fault indicated on figure 1b. The depth constraint on this event is within ± 500 meters and indicates a depth at the top of the geopressured zone. Figure 4, on the other hand, is an example of a slow-rupture-velocity, low-stress-drop microearthquake recorded at the Brazoria array on 1 January 1981. The hypocenter is well constrained and suggests that the more likely form of rupture well above the geopressured zone may be a slow movement,

possibly very nearly a gravity slide phenomenon. It is possible that the observed rumble activity is an extension of this phenomenon to even slower processes (see figure 5).

(2) The outward and upward migration of seismicity following shut-ins at the Brazoria test well may suggest a propagating stress relaxation front which could be very important to understanding time delays of fault-controlled subsidence. The fact that nearly all microearthquakes show strong affinity to growth faults would support the observations of Kreitler (1976) that subsidence is controlled by local faults in the Houston-Galveston area.

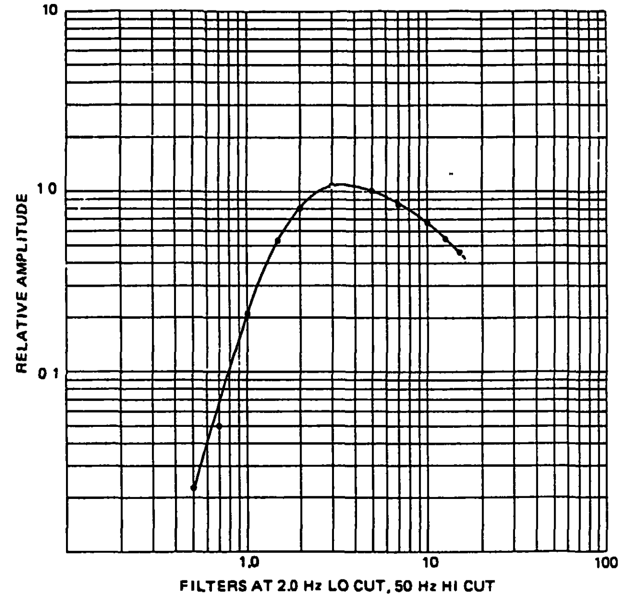


Figure 2. Seismic System Velocity response.

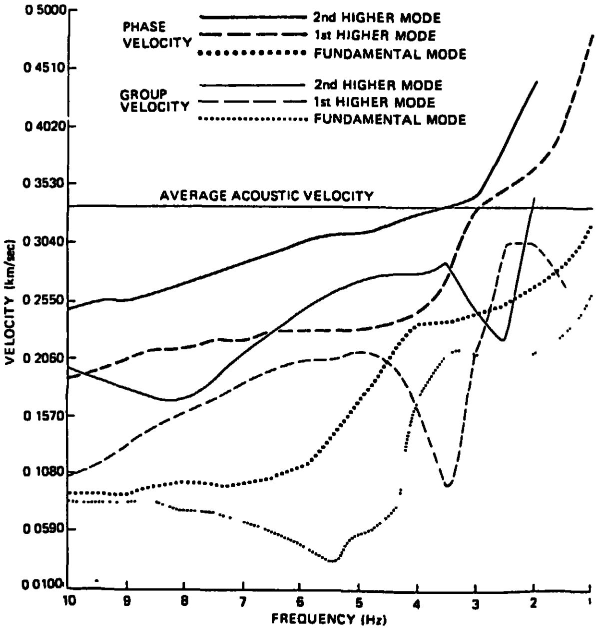
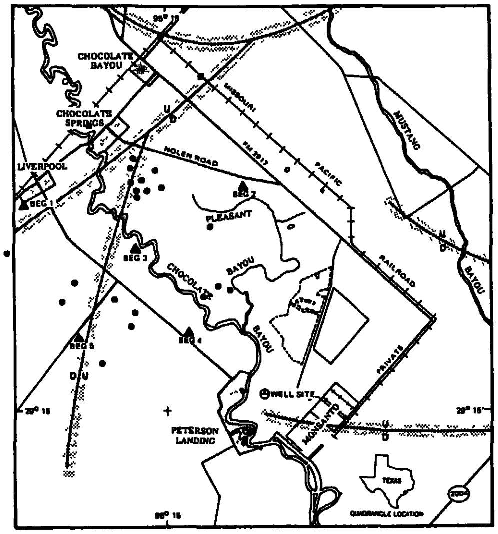
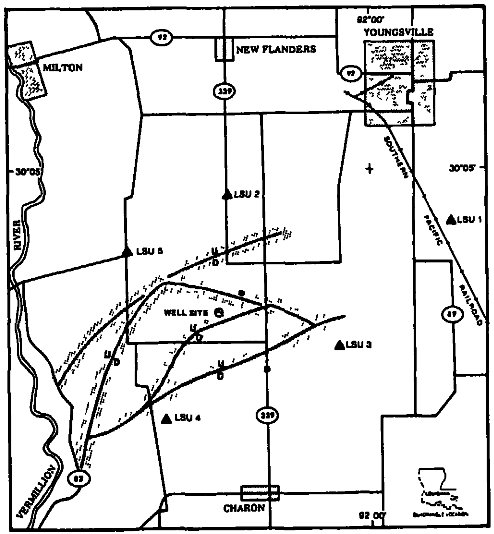


Figure 6. Rayleigh wave phase and group velocities for the Texas and Louisiana coast.

(3) The affinity of Brazoria seismicity to the north-south trending growth fault which passes between BEG3 and BEG5 (see figure 1a) may indicate that this is a significant linear permeability barrier and will limit the production of brines to the east of the fault. If this is the case, then it may be possible to define reservoir dimensions using such induced activity. Further, if activity continues to be confined to this particular fault, it may indicate the most likely region for future concentrated subsidence studies.



1.a Seismic events at Pleasant Bayou, Texas from January to July 1981



1.b Seismic events at Bayou Parcperdue, Louisiana from August 1980 to July 1981

1 .5 0 1 2 3 4 MILES
1 .5 0 1 2 3 4 5 KILOMETERS

▲ SEISMOGRAPH STATIONS

⊖ TEST WELL

GROWTH FAULTS NEAR 16,000 FT DEPTH

• SEISMIC EVENTS

Figure 1. a. Brazoria seismic array
b. Parcperdue seismic array

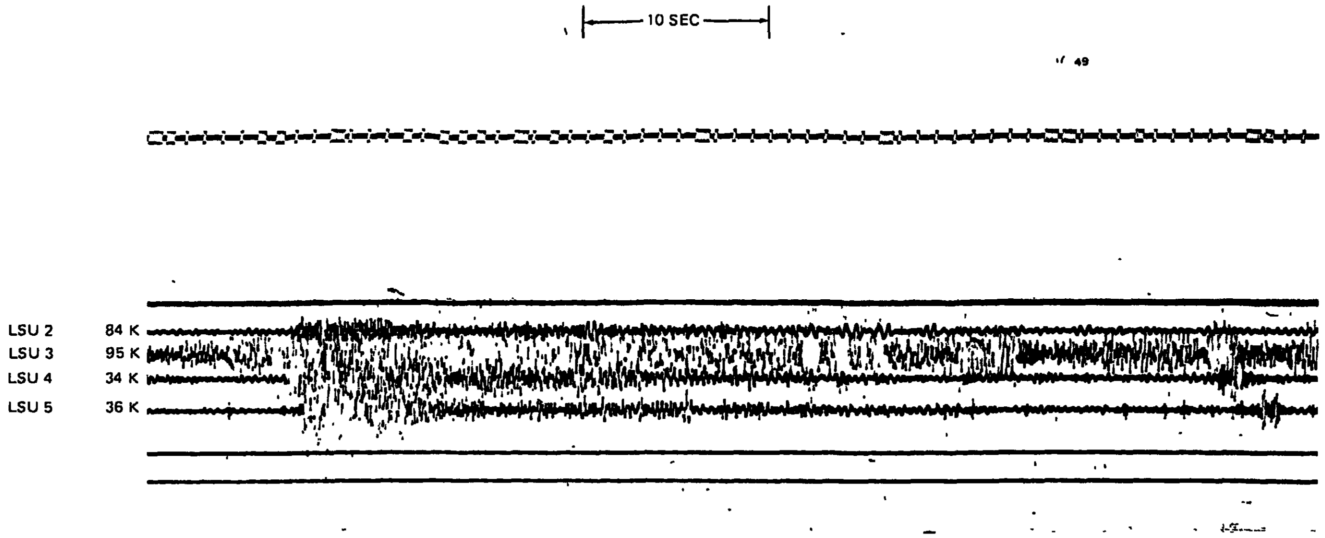


Figure 3. 27 March 1981 earthquake origin time 17;48 = 16142 UCT (CST + 6 hrs), magnitude $M_L = 1.3, M_D = 1.4$.

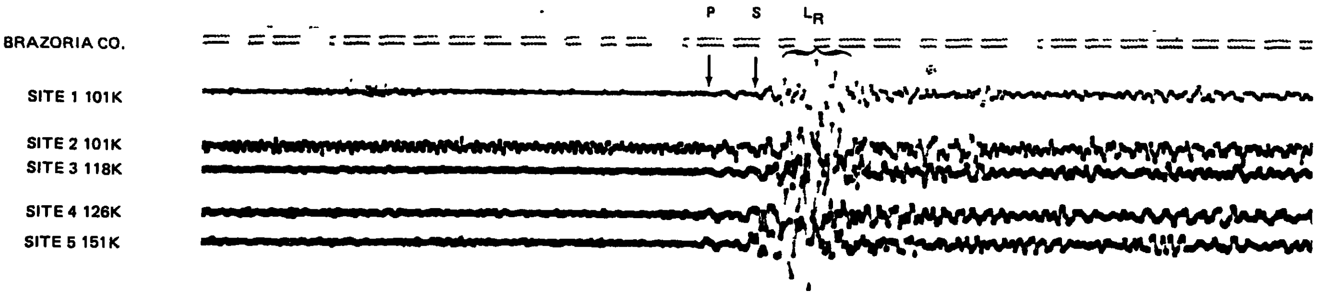


Figure 4. Background noise samples with microseismic event (magnitude 1.6), 1 January 1981 03:32:29.29 UCT (31 December 1980 21:32:29.29 CST).

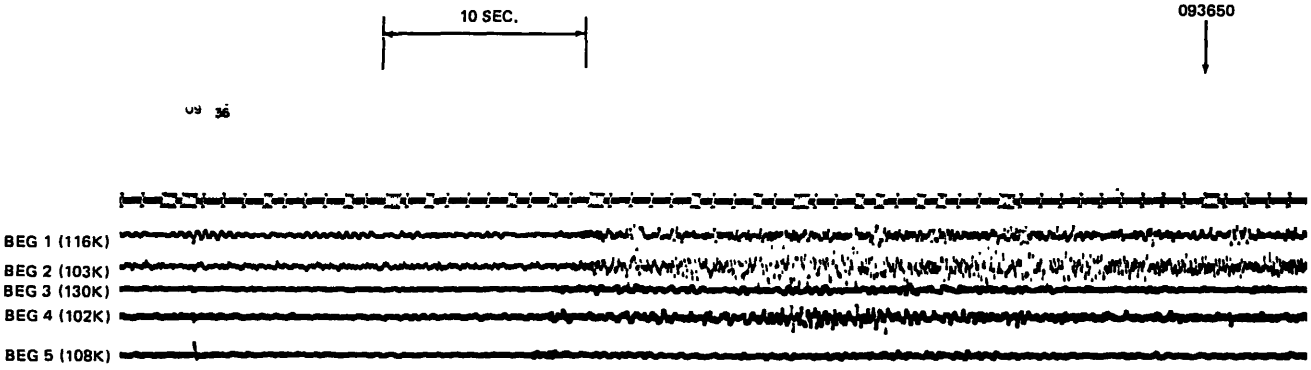


Figure 5. Event 25 May 1981. Rumble event with no clear onset.